ZooKeys 431: 61–78 (2014)
doi: 10.3897/zookeys.431.7474
www.zookeys.org

DATA PAPER

A peer-reviewed open-access journal
ZooKeys
Launched to accelerate biodiversity research

Scale Insects, edition 2, a tool for the identification of potential pest scales at U.S.A. ports-of-entry (Hemiptera, Sternorrhyncha, Coccoidea)

Douglass R. Miller[1], Alessandra Rung[2], Grishma Parikh[2,3]

1 *Systematic Entomology Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD 20705, USA* **2** *Plant Pest Diagnostics Branch, California Department of Food and Agriculture, Sacramento, CA 95832, USA* **3** *California Agricultural Support Services, Sacramento, CA 95811, USA*

Corresponding author: *Alessandra Rung* (arung@cdfa.ca.gov)

Academic editor: *Vishwas Chavan* | Received 11 March 2014 | Accepted 24 July 2014 | Published 6 August 2014

http://zoobank.org/5C316754-331B-4A09-A1B0-EF8BFEB0113C

Citation: Miller DR, Rung A, Parikh G (2014) Scale Insects, edition 2, a tool for the identification of potential pest scales at U.S.A. ports-of-entry (Hemiptera, Sternorrhyncha, Coccoidea). ZooKeys 431: 61–78. doi: 10.3897/zookeys.431.7474

Abstract

We provide a general overview of features and technical specifications of an online, interactive tool for the identification of scale insects of concern to the U.S.A. ports-of-entry. Full lists of terminal taxa included in the keys (of which there are four), a list of features used in them, and a discussion of the structure of the tool are provided. We also briefly discuss the advantages of interactive keys for the identification of potential scale insect pests. The interactive key is freely accessible on http://idtools.org/id/scales/index.php

Keywords

Agricultural pest, Coccoidea, Interactive key, Identification tool, Lucid, Scale insects

Copyright *Douglass R. Miller et al.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Introduction

Scale insects include notorious invasive species. They are small, often live in concealed portions of their hosts, and are transported in commodities that are common in international trade (Miller et al. 2002). Scales cause billions of dollars in damage to U.S. crops and in control costs annually (Kosztarab 1977, 1990; Kondo et al. 2008) and nearly all damaging scale pests are species that were inadvertently introduced (Miller et al. 2002; Miller and Miller 2003).

Only a few specialists in the world can identify scale insects based on morphology. Of these, many are retired or approaching retirement, putting scale insect systematics in danger of being stifled by inadequate manpower (Kondo et al. 2008; Hardy 2013). Moreover, because scale insect pests may arrive from all over the world (Miller et al. 2014), regional expertise and scale insect diagnostic tools with a regional focus are inadequate for border patrol (Hardy 2013). Considering the common presence of scales in interceptions (Evans and Dooley 2013), we have produced a user-friendly, online tool that can be used at U.S.A. ports-of-entry to help with the identification of potentially invasive species.

Although many dichotomous keys have been developed for scales (Hardy 2013), they are regional in scope and do not have the flexibility of interactive keys. For instance, in traditional dichotomous keys, features appear in a fixed order, whereas in Lucid-based and other interactive keys, there are many paths to a correct identification. This is advantageous because some features are difficult to interpret, difficult to see on the specimen in hand, or are absent in a damaged specimen. Another benefit of interactive keys over dichotomous keys is that the user can express uncertainty by selecting more than one state per character, and view/modify the character states already selected (Walter and Winterton 2007; Cerretti et al. 2012; Dallwitz et al. 2013).

An earlier version of Scale Insects comprising 148 species was published on CDROM and uploaded to the USDA web site in 2007 (Miller et al. 2007). It was mentioned as useful by Hardy (2013) and has been part of training programs for state and federal identifier workshops, being often used by U.S. port personnel for making identifications (Greggory Evans, APHIS identifier, personal communication, 2014). The new edition includes 46 additional species, and updated information on the distribution of previously included species. Furthermore, the key to families was updated with new findings in the higher classification of scale insects (e.g., Hodgson 2012). The new tool also differs from the old one in how the glossary (pages containing pest-specific information) and the fact sheets are generated: in the old tool, fact sheets and the glossary are static html pages, whereas in the new tool they are dynamically generated and thus can be more easily updated.

As far as we know, one other Lucid key, with a regional scope, is available online to identify scales (Hardy and Kondo 2009). The general structure of Scale Insects, edition 2 emulates a number of Lucid-based tools for pest identification created

and/or funded by the USDA Animal and Plant Health Inspection Service (APHIS), Identification Technology Program (ITP), and which can be found at http://id-tools.org/id/. Our tool differs from all of them by being extensively linked to a comprehensive database on scale insects, ScaleNet (Ben-Dov et al. 2012). ScaleNet is unusual in that it is not only a specimen database *per se*, but a complex model of the scale insect literature (*c.* 25,000 references) (Hardy 2013). The links to ScaleNet give the user instant access to updated taxonomy, distribution and host records, and literature citations.

Despite the usefulness of Scale Insects, edition 2, it must be emphasized that it contains only a small subset of the world scale fauna. According to ScaleNet there are 7,792 species of scale insects worldwide. Therefore, a species that is not represented in the tool may key out as one that is (a false positive identification). For this reason, identifications should always be checked against information on the fact sheets and compared against authoritatively identified reference specimens for further assessment.

The following groups are represented in Scale Insects, edition 2 (Miller et al. 2014): Scale Families, encompassing the families most often encountered at the U.S.A. ports-of-entry; Soft Scales; Mealybugs and Mealybug-like families; and Other Scales, encompassing pests in various families with the exclusion of the Diaspididae. The tool makes extensive use of hypertext to link to images, glossaries, and other support material, and has four main components: Lucid-based interactive keys, fact sheets, glossary of morphological terms, and image gallery.

Format of the paper

This paper was written following the outlines for data papers provided by Penev et al. (2009, 2012) and the format was inspired on Cerretti et al. (2012) and Chrétiennot-Dinet et al. (2014).

Project description

There are four keys in Scale Insects, edition 2: Scale families, Mealybugs and Mealybug-like families, Soft Scales, and Other Scales (details for each key provided below). Terminal taxa in these keys are potential pests to U.S.A. agriculture, from all over the world, and were selected from a list of interceptions by APHIS-Plant Protection and Quarantine (PPQ) between 1995 and 2013. This list can be obtained from APHIS upon request, but has not been published. Below we describe the taxonomic coverage of each key, and provide lists of the features used to discriminate taxa in them. Features in the keys are from the adult female, are standard in scale insect taxonomy (Kondo et al. 2008) and, for the most part, can only be seen on a slide-mounted specimen.

Scale Families key

General features

The key matrix is based on 66 morphological features of the adult female and includes 33 extant families as terminal taxa.

List of the terminal taxa included in the current version

Aclerdidae; Asterolecaniidae; Beesoniidae; Callipappidae; Carayonemidae; Cerococcidae; Coccidae; Coelostomidiidae; Conchaspididae; Dactylopiidae; Diaspididae; Eriococcidae, Halimococcidae; Kermesidae; Kerriidae; Kuwaniidae; Lecanodiaspididae; Marchalinidae; Margarodidae; Matsucoccidae; Micrococcidae; Monophlebidae; Ortheziidae; Phenacoleachiidae; Phoenicococcidae; Pityococcidae; Polliniinae; Pseudococcidae; Putoidae; Rhizoecidae; Steingeliidae; Stictococcidae; Xylococcidae.

Features used in the key

The morphological features to separate among scale families are listed in Table 1. They were largely taken from the works mentioned below, from isolated descriptions, and analysis of specimens: Aclerdidae (McConnell 1954); Asterolecaniidae (Stumpf and Lambdin 2006); Cerococcidae (Lambdin and Kosztarab 1977); Coccidae (Hodgson 1994); Conchaspididae (Mamet 1954); Dactylopiidae (De Lotto 1974); Diaspididae (Danzig 1993; Takagi 1960); Eriococcidae (Kozár et al. 2013); Kermesidae (Bullington and Kosztarab 1985); Kerriidae (Chamberlin 1923); Lecanodiaspididae (Borchsenius 1960; Howell and Kosztarab 1972); Margarodidae (Jakubski 1965); Monophlebidae (Morrison 1928); Ortheziidae (Kozár 2004); Pseudococcidae (Williams and Granara de Willink 1992); Putoidae (McKenzie 1967); Rhizoecidae (Kozár and Konczné Benedicty 2007); Stictococcidae (Richard 1971, 1976).

Soft Scales

General features

The key matrix is based on 41 morphological features and includes 48 species in 21 genera of Coccidae.

Table 1. Features used in the Key to Scale Insect families of Scale Insects, edition 2. Features are listed according to the main region of the body where they occur. "General features" are present in at least two different main body regions. Abbreviations: QP, quinquelocular pores.

Location in body	Features
General features	Cerarii (presence); marginal setae (presence); size of abdominal spiracles with respect to thoracic spiracles; tubular ducts (presence; shape of tubular duct invagination), invaginated tubular duct in QP clusters (presence); 8-shaped pores (presence), predominant pore type; ornate setae over dorsum (presence).
Head	Number of labial segments. Number of antennal segments, campaniform sensilla on second antennal segment (presence and number), antennal bar (presence and shape), length of basal antennal segment with respect to others, basal antennal segment sclerotization (presence), reticulate pattern of antenna (presence), antennal articulatory process on first segment (presence), shape of apical antennal segment, enlarged seta on apex of antenna (presence).
Thorax	Size of first pair of thoracic spiracles with respect to second pair; bar or sclerotized area on spiracle (presence); pores in atrium of thoracic spiracles (presence and number); thoracic spiracles close to anal opening (presence); ocellar spot (presence); row of pores in spiracular furrow (whether defined or not); spiracular setae (presence); metasternal sclerotization (presence). Legs. Whether present, developed or reduced; length of front legs with respect to mid and hind legs; trochanter pores on each surface (presence and number), distribution of trochanter pores; fusion between trochanter and femur (presence); coxal structure, whether divided longitudinally or not; fusion between tibia and tarsus (presence); number of setae on hind tibia; clubbed setae on distal end of tibia (presence); number of tarsal segments, shape of tarsus, clubbed tarsal digitules (presence, arrangement), campaniform sensilla on tarsus (presence); claw (presence), claw digitules (presence and shape), claw denticles (presence, shape and number), basal claw denticle (presence); translucent pores on hind legs (presence).
Abdomen	Number of abdominal spiracles; relative size of first six abdominal spiracles with respect to last two; pores in abdominal spiracles (presence); anal opening position; anal tube sclerotization (degree, position); number of anal ring setae; anal ring pores (presence and location); anal plate(s) (presence, number, position); anal cleft (presence); arch plate (presence); lateral sclerotized bar near anal ring (presence); anal lobes (shape) and presence of setae on projecting anal lobes; anal opening position on body; cicatrices (presence); cribriform plates (presence); circulus (presence); dorsomedial spine anterior of anal ring (presence); marginal crenulations (presence); ostioles (presence), pygidium (presence); vulvar orientation.

List of the terminal taxa included in the current version

Ceroplastes ceriferus (Fabricius, 1798); *C. cirripediformis* Comstock, 1881; *C. floridensis* Comstock, 1881; *C. japonicus* Green, 1921; *C. rubens* Maskell, 1893; *C. rusci* (Linnaeus, 1758); *C. sinensis* Del Guercio, 1900; *C. stellifer* (Westwood, 1871); *Coccus capparidis* (Green, 1904); *C. hesperidum* Linnaeus, 1758; *C. longulus* (Douglas, 1887); *C. moestus* De Lotto, 1959; *C. pseudohesperidum* (Cockerell, 1895); *C. viridis* (Green, 1889); *Drepanococcus chiton* (Green, 1909); *Eucalymnatus tessellatus* (Signoret, 1873); *Kilifia acuminata* (Signoret, 1873); *K. americana* Ben-Dov, 1979; *K. deltoides* De Lotto, 1965;

Marsipococcus proteae (Brain, 1920); *Megapulvinaria maxima* (Green, 1904); *Milviscutulus mangiferae* (Green, 1889); *Parasaissetia nigra* (Nietner, 1861); *Parthenolecanium corni* (Bouché, 1844); *Phalacrococcus howertoni* Hodges & Hodgson, 2010; *Philephedra broadwayi* (Cockerell, 1896); *P. lutea* (Cockerell, 1893); *P. tuberculosa* Nakahara & Gill, 1985; *Prococcus acutissimus* (Green, 1896); *Protopulvinaria longivalvata* Green, 1909; *P. pyriformis* (Cockerell, 1894); *Pseudokermes vitreus* (Cockerell, 1894); *Pulvinaria floccifera* (Westwood, 1870); *P. hydrangeae* Steinweden, 1946; *P. ixorae* Green, 1909; *P. polygonata* Cockerell, 1905; *P. psidii* Maskell, 1893; *P. urbicola* Cockerell, 1893; *Pulvinariella mesembryanthemi* (Vallot, 1829); *Saissetia coffeae* (Walker, 1852); *S. miranda* (Cockerell & Parrott, 1899); *S. neglecta* De Lotto, 1969; *S. oleae* Olivier, 1791; *Taiwansaissetia formicarii* (Green, 1896); *Tillancoccus tillandsiae* Ben-Dov, 1989; *T. mexicanus* Ben-Dov, 1989; *Udinia catori* (Green, 1915); *U. farquharsoni* (Newstead, 1922).

Features used in the key

The morphological features to separate among soft scale pests are listed in Table 2. They were largely extracted from the comprehensive works of De Lotto (1965), Gill (1988), Gill et al. (1977), Gimpel et al. (1974), Hamon and Williams (1984), Hodgson (1994), and Williams and Watson (1990), from isolated descriptions, and analysis of specimens.

Mealybugs and Mealybug-like families

General features

The key matrix is based on 44 morphological features and covers 99 species in 27 genera and three families (96 species in 24 genera in Pseudococcidae, two species in one genus of Putoidae, and one species and one genus of Rhizoecidae).

List of the terminal taxa included in the current version

Pseudococcidae (Mealybugs): *Antonina graminis* (Maskell, 1897); *A. nakaharai* Williams & Miller, 2002; *Balanococcus diminutus* (Leonardi, 1918); *Brevennia rehi* (Lindinger, 1943); *Chaetococcus bambusae* (Maskell, 1893); *Crisicoccus azaleae* (Tinsley, 1898); *Delottococcus aberiae* (De Lotto, 1961); *D. confusus* (De Lotto, 1977); *Dysmicoccus boninsis* (Kuwana, 1909); *D. brevipes* (Cockerell, 1893); *D. grassii* (Leonardi, 1913); *D. lepelleyi* (Betrem, 1937); *D. mackenziei* Beardsley, 1965; *D. neobrevipes* Beardsley, 1959; *D. orchidum* Williams, 2004; *D.* sp. nr. *texensis*; *D. sylvarum* Williams & Granara de Willink, 1992; *D. wistariae* (Green, 1923); *Exallomochlus camur* Williams, 2004; *E. hispidus* (Morrison, 1921); *E. philippinensis* Williams, 2004; *Ferrisia dasylirii*

Table 2. Features used in the Key to Soft Scales of Scale Insects, edition 2. Features are listed according to the main region of the body where they occur. "General features" are present in at least two different main body regions. Abbreviations: MP, multilocular pores.

Location in body	Features
General features	Body shape; dermal reticulation in mature females (presence); dorsal setae (presence, shape, thickness); filamentous ducts on body margin (presence); marginal setae thickness, shape at apex; tubular ducts (presence overall), distribution on venter, presence on dorsum; submarginal tubercles (presence and distribution).
Head	Number of long setae between antennae. Number of antennal segments.
Thorax	Stigmatic setae (whether differentiated or not, length, number); number of rows of stigmatic setae, whether rows contiguous between spiracles or not; MP anterior of anterior spiracle (presence, size with respect to other MPs); number of marginal setae between anterior spiracular furrows. Legs. Whether present and developed; cavity on mid and hind coxae (presence); claw denticle (presence); tibio-tarsal sclerosis (presence); tibio-tarsal spur on hind leg (presence and development); relative sizes of claw digitules.
Abdomen	Anal plate (shape, position, number of apical, subapical, discal and subdiscal setae); anal plate protuberance (presence); fringe setae (total number); preopercular pores (presence, distribution); number of elongate prevulvar setae; MP distribution, number of loculi in MP near vulva.

(Cockerell, 1896); *F. malvastra* (McDaniel, 1962); *F. terani* Williams & Granara de Willink, 1992; *F. virgata* (Cockerell, 1893); *Formicococcus njalensis* (Laing, 1929); *F. polysperes* Williams, 2004; *F. robustus* (Ezzat & McConnell, 1956); *Hordeolicoccus heterotrichus* Williams, 2004; *H. nephelii* (Takahashi, 1939); *Hypogeococcus pungens* Granara de Willink, 1981; *Laminicoccus pandani* (Cockerell, 1895); *Maconellicoccus hirsutus* (Green, 1908); *M. multipori* (Takahashi, 1951); *Nipaecoccus annonae* Williams & Granara de Willink, 1992; *N. jonmartini* Williams & Granara de Willink, 1992; *N. nipae* (Maskell, 1893); *N. viridis* (Newstead, 1894); *Palmicultor browni* (Williams, 1960); *P. palmarum* (Ehrhorn, 1916); *Paracoccus burnerae* (Brain, 1915); *P. ferrisi* Ezzat & McConnell, 1956; *P. herreni* Williams & Granara de Willink, 1992; *P.interceptus* Lit, 1997; *P. lycopersici* Ezzat & McConnell, 1956; *P. marginatus* Williams & Granara de Willink, 1992; *P. mexicanus* Ezzat & McConnell, 1956; *P. solani* Ezzat & McConnell, 1956; *Paraputo guatemalensis* (Ferris, 1953); *P. odontomachi* (Takahashi, 1951); *P. olivaceus* (Cockerell, 1896); *Phenacoccus defectus* Ferris, 1950; *P. franseriae* Ferris, 1921; *P. gossypii* Townsend & Cockerell, 1898; *P. hakeae* Williams, 1985; *P. helianthi* (Cockerell, 1893); *P. madeirensis* Green, 1923; *P. parvus* Morrison, 1924; *P. solani* Ferris, 1918; *P. solenopsis* Tinsley, 1898; *P. stelli* (Brain, 1915); *Planococcus citri* (Risso, 1813); *P. ficus* (Signoret, 1875); *P. halli* Ezzat & McConnell, 1956; *P. kraunhiae* (Kuwana, 1902); *P. lilacinus* (Cockerell, 1905); *P. litchi* Cox, 1989; *P. minor* (Maskell, 1897); *Pseudococcus aurantiacus* Williams, 2004; *P. baliteus* Lit, 1994; *P. calceolariae* (Maskell, 1879); *P. comstocki* (Kuwana, 1902); *P. cryptus* Hempel, 1918; *P. dendrobiorum* Williams, 1985; *P. elisae* Borchsenius, 1947; *P. jackbeardsleyi* Gimpel & Miller, 1996; *P. landoi* (Balachowsky, 1959); *P. longispinus* (Targioni Tozzetti, 1867); *P. lycopodii* Beardsley, 1959;

P. maritimus (Ehrhorn, 1900); *P. microcirculus* McKenzie, 1960; *P. nakaharai* Gimpel & Miller, 1996; *P. odermatti* Miller & Williams, 1997; *P. philippinicus* Williams, 2004; *P. pithecellobii* Gimpel & Miller, 1996; *P. solenedyos* Gimpel & Miller, 1996; *P. viburni* (Signoret, 1875); *Rastrococcus iceryoides* (Green, 1908); *R. invadens* Williams, 1986; *R. spinosus* (Robinson, 1918); *Saccharicoccus sacchari* (Cockerell, 1895); *Spilococcus mamillariae* (Bouché, 1844); *Vryburgia amaryllidis* (Bouché, 1837); *V. distincta* (De Lotto, 1964); *V. succulentarum* Williams, 1985; *V. viator* (De Lotto, 1961). **Putoidae** (Giant mealybugs): *Puto barberi* (Cockerell, 1895); *P. mexicanus* (Cockerell, 1893).**Rhizoecidae** (Ground mealybugs): *Rhizoecus amorphophalli* Betrem, 1940.

Features used in the key

When the user first opens the Mealybugs and Mealybug-like Families key, he/she will be prompted to choose among the following families in the features window (in order to use this key, the user must know the family classification of the specimen): Pseudococcidae, Rhizoecidae or Putoidae. After the appropriate family has been selected, the features that differentiate among the species included in that family will open. While most features separate among species of Pseudococcidae, one character (presence/absence of tubular ducts in cerarii) is used to separate between the two species of Putoidae. This character was only coded for putoids. Since Rhizoecidae is represented by only one species (above), choosing this family will automatically result in species identification.

Morphological features used to separate among species of Pseudococcidae are listed in Table 3 and were largely taken from the comprehensive works of Ferris (1950), McKenzie (1967), Miller and McKenzie (1973), Miller (1975), Cox (1987, 1989), Williams and Watson (1988), Kosztarab (1996), Williams and Miller (2002), Miller and Giliomee (2011), Kaydan and Gullan (2012), Williams (2004), from isolated descriptions, and the analysis of specimens. Features to separate Putoidae species were taken from Williams and Granara de Willink (1992).

Other scales

General features

The key matrix is based on 41 morphological features and covers 47 species (entities) in 26 genera and 11 families.

List of the terminal taxa included in the current version

Family names, in bold, are not terminal taxa, but were added below to help situate the different species in the higher classification.

Table 3. Features used to separate Pseudococcidae species in Scale Insects, edition. Features are listed according to the main region of the body where they occur. "General features" are present in at least two different main body regions. Abbreviations: DP, discoidal pores, MP, multilocular pores, ORTD, oral-rim tubular ducts, OCTD, oral-collar tubular ducts, TP, trilocular pores.

Location in body	Features
General features	Cerarii (presence, number on each side of body); ORTD (presence overall, presence on venter, number on dorsum); MP on dorsum (presence); OCTD on dorsum (presence); TP (presence and position); *Ferrisia*-like rim around tubular ducts (presence), position of DP in rim of *Ferrisia*-like tubular ducts, position of setae in rim of *Ferrisia*-like tubular ducts, sclerotization around *Ferrisia*-like tubular ducts (named A and B in key); QP (presence, position)
Head	Head: ORTD (presence on frontal dorsal region, presence on dorsomarginal region between cerarii 15-16); cerarii on head and/or prothorax (presence); DP near eye (presence); number of OCTD between antennae. Number of antennal segments
Thorax	Thorax: ORTD (number laterad of mid coxa, presence of cluster between front coxa and body margin); spiracular pores (presence); DP on derm surrounding hind coxa (presence); MP (presence on dorsal mid-thorax). Legs (presence); translucent pores on hind legs (presence and position); denticle on claw (presence)
Abdomen	Abdomen: anal bar (presence); auxiliary filamentous setae in 2nd cerarius (presence); conical setae in abdominal cerarii (presence); circulus (presence, shape); presence of dorsomedial cerarii; shape of cerarian setae; number of conical setae in anal lobe cerarii; setae on dorsum of segment VIII longer than on segments VII and VI (presence); shape and length of dorsal setae; MP (presence on ventrolateral abdominal portion, on abdominal segments I-VIII); dorsal ORTD (presence near lateral margin of most abdominal segments, number on abdomen)

Aclerdidae (Flat grass scales): *Aclerda takahashii* Kuwana, 1930; *A. sacchari* Teague, 1925. **Asterolecaniidae** (Pit scales): *Asterolecanium epidendri* (Bouché, 1844); *Bambusaspis bambusae* (Boisduval, 1869); *B. miliaris* (Boisduval, 1869); *Palmaspis inlabefacta* (Russell, 1941); *P. phoenicis* (Ramachandra Rao, 1922); *Planchonia stentae* (Brain, 1920); *Russellaspis pustulans* (Cockerell, 1892); *Sclerosococcus ferrisi* McKenzie, 1958; *S. tillandsiae* Lambdin, 1980. **Conchaspididae** (False armored scales): *Conchaspis angraeci* Cockerell, 1893; *C. capensis* (Linnaeus, 1763); *C. orchidarum* Mamet, 1954. **Dactylopiidae** (Cochineal scales): *Dactylopius coccus* Costa, 1829; *D. confusus* (Cockerell, 1893); *D. opuntiae* (Cockerell, 1896); *D. tomentosus* (Lamarck, 1791). **Eriococcidae** (Felt scales): *Asiacornococcus kaki* (Kuwana, 1931); *Acanthococcus araucariae* (Maskell, 1879); *A. coccineus* (Cockerell, 1894); *A. dubius* (Cockerell, 1896); *Ovaticoccus agavium* (Douglas, 1888). **Kerriidae** (Lac scales): *Kerria lacca* (Kerr, 1782); *Paratachardina pseudolobata* (Kondo & Gullan, 2007). **Lecanodiaspididae** (False pit scales): *Lecanodiaspis dendrobii* (Douglas, 1892); *L. prosopidis* (Maskell, 1895); *Psoraleococcus multipori* (Morrison, 1921). **Matsucoccidae** (Pine bast scales): *Matsucoccus feytaudi* Ducasse, 1941; *M. josephi* Bodenheimer & Harpaz, 1955; *M. matsumurae* (Kuwana, 1905). **Monophlebidae** (Giant scales): *Crypticerya genistae* (Hempel, 1912); *C. rosae* (Riley & Howard, 1890); *Drosicha* sp.; *Icerya aegyptiaca* (Douglas, 1890); *I. pulchra* (Leonardi, 1907); *I. purchasi* Maskell, 1879; *I. samaraia* (Morrison, 1927); *I. seychellarum* (Westwood, 1855). **Ortheziidae** (Ensign scales): *Insignorthezia insignis* (Browne, 1887); *I. pseudinsignis* (Morrison, 1952); *Newsteadia floccosa* (De Geer, 1778); *Ortheziola vejdovskyi* Šulc, 1895; *Praelongorthezia praelonga* (Douglas, 1891). **Stictococcidae** (Stictococcids): *Stictococcus formicarius* Newstead, 1910; *S. intermedius* Newstead, 1917; *S. sjostedti* Cockerell, 1903.

Features used in the key

As with the Key to Mealybugs and Mealybug-like families, the first feature of this key is family, of which there are 11. Therefore, to use this key the user needs to determine the family first, using the Key to families. Morphological features used to separate among species of the families listed below are presented in Table 4, and were largely taken from the literature (cited below after each family):

Aclerdidae: McConnell (1954). **Asterolecaniidae**: Stumpf and Lambdin (2006). **Conchaspididae:** Mamet (1954). **Dactylopiidae:** De Lotto (1974). **Eriococcidae:** Kozár et al. (2013). **Kerriidae:** Chamberlin (1923)**. Lecanodiaspididae:** Borchsenius (1960), Howell and Kosztarab (1972). **Matsucoccidae:** Foldi (2005). **Monophlebidae:** Morrison (1928). **Ortheziidae:** Kozár (2004). **Stictococcidae:** Richard (1971, 1976). Additional features were taken from isolated descriptions, and analysis of specimens.

Technical specifications

Web location: http://idtools.org/id/scales/index.php
Platform: a website
Web Server: CentOS
Programming language: PHP 5 and MySQL
Application version: 2.0
Data base: MySQL
Data: 2.0
Language: English
License for use of the key: Attribution-Non-commercial
Use of the primary data: available upon request.

The keys were directly built in Lucid builder (various versions up to 2007), then updated on Builder 3.5 (available at http://lucidcentral.org, Queensland, Australia) for the current version. A list of the Lucid3 key files (key data files and key program files) can be found in Penev et al. (2009).

Keys were deployed online using the Lucid Key Server (available at http://lucidcentral.org). The On-line Player is an alternative to the Lucid3 Application Player for interactive keys created using the Lucid3 Builder. Playing keys using the Lucid On-line Player does not require Java installation. This method may be advantageous to government workers because Java applications are often partially or totally blocked in government computers due to security concerns. Furthermore, some keys deployed using the Lucid3 Player may temporarily stop working or work defectively after a Java update, or may not work properly until an update has been implemented. However, it must be emphasized that the not all features of the Lucid3 Player are available in the On-line Player. For instance, the function to "prune redundant features" has been im-

Table 4. Features used in the Key Other Families of Scale Insects, edition 2. Features are listed according to the main region of the body where they occur. "General features" are present in at least two different main body regions. Abbreviations: DP, discoidal pores, QP, quinquelocular pores.

Family	Features
Aclerdidae	Dorsal or ventral microducts on marginal areas of head, thorax, and abdomen (dorsal or ventral position).
Asterolecaniidae	dorsal 8-shaped pores (presence and position, sizes, excluding lateral ones); marginal 8-shaped pores (presence); dorsal 8-shaped tubular ducts (presence); submarginal DPs (presence); MP distribution on ventromedial areas; submarginal QP row between antennae (presence, whether complete); pear shaped anal lobe sclerotization (presence); dorsal tubes (presence); number of setae on each side of anal ring; sclerotization of apex of abdomen (degree).
Conchaspididae	Number of MPs on abdominal segment 3; tubular ducts (presence).
Dactylopiidae	Size of enlarged setae in longitudinal lines; tubular ducts in QP cluster (presence); anal ring sclerotization (presence).
Eriococcidae	QP on dorsum (presence); arrangement of enlarged setae (presence); bifurcation of microtubular duct orifice (presence); number of antennal segments; anal ring pores (presence)
Kerriidae	Shape of body
Lecanodiaspididae	Two long setae anterior of vulva (presence); number of cribriform plates on each side of the body.
Matsucoccidae	Enlarged setae on 5th antennal segment (presence); number of rows of cicatrices
Monophlebidae	Open center pores (presence); cicatrices (number, size); number abdominal spiracles; ovisac band or marsupium band (presence); marsupium (presence)
Ortheziidae	Sclerotization on head (presence, width); number of antennal segments; dorsomedial wax plates medially (presence and reach to marginal plates); bands of spines within ovisac band (presence); fusion between tibia and tarsus (presence)
Stictococcidae	Enlarged marginal seta fringing (presence and number of projections); dorsal submarginal seta fringing (presence); shape of dorsal submarginal seta

plemented in the former but not in the latter. Moreover, while the help icon (?) of the Lucid 3 Player is linked to a help file online, the help icon of the Lucid Online Player is linked to the Lucid webpage on (http://www.lucidcentral.org/en-us/software/lucid3.aspx); from there the user has to find the help file that has been written for the Lucid3 player. Despite those caveats, we believe that the On-line Player is a work in progress, and that in the long run the advantages of using it will outweigh the disadvantages of the Java player. A thorough discussion of the differences between the two programs for playing Lucid keys is warranted.

Information in fact sheets and glossary is managed using the Fact Sheet Manager (FSM), an interface for a database that stores all the data present in the dynamic pages of the website (fact sheets and glossary of terms). Both FSM and the database have been created and are maintained by the Identification Technology Program (ITP), USDA APHIS PPQ. When the user chooses an entity (by selecting a link of a particular species), a single fact sheet page that is coded with queries to the database populates the appropriate fact sheet content. This contrasts with the static HTML fact sheets in the previous version of Scale Insects (Miller et al. 2007), and allows for quick updates and corrections that go online almost immediately.

SCALE INSECTS
home
about
fact sheets
keys
gallery
glossary
Identification Tool for Species of Quarantine Significance, Edition 2
Mango shield scale
Milviscutulus mangiferae
This polyphagous pest has been intercepted numerous times on a variety of hosts from Pacific islands, South and Southeast Asia, Central America, and the Caribbean. Mango shield scales occur primarily on the leaves of their hosts. Males are usually absent or rare, and the females are yellow-green when new, turning brown as they grow older, and lacking an obvious wax covering.
search fact sheets...
Go
Find a fact sheet
Detailed diagnostic information and images are presented in fact sheets for each family and species represented. The fact sheets have been updated with the latest taxonomic and quarantine information.
See the fact sheets »
Identify a scale
There are four separate keys to identify slide-mounted adult females: one for scale families, one for mealybugs and mealybug-like scales, one for soft scales, and one for pest species in other families.
Use one of the keys »
View the image gallery
A comprehensive image gallery is included. The gallery is filterable, offering an image-based option to find the pest fact sheet you're looking for. Each image links directly to the fact sheet in which it's found.
Explore the gallery »
1
Scale Insects, Edition 2
Last updated April 2014
SCALENET
USDA
cdfa
Lucid

Figure 1. Screen snapshot of the home page of Scale Insects, edition 2 (viewed from Firefox 27.0.1 on April 10, 2014).

Tool details

In the portal Scale Insects, edition 2, the user has the option to find a fact sheet, use one of the keys, view the image gallery or consult the glossary of morphological terms (Fig. 1).

Searching for a family in the "search fact sheets" box will list a fact sheet for that family and for the corresponding species in one of the keys, if present. For instance, a search for Aclerdidae will find three fact sheets, one for Aclerdidae in the Families key and two for species of *Aclerda* Signoret in the Other Scales key. Fact sheets in keys to species contain the following information: a link to a Catalog on ScaleNet, Common name, Field characters (diagnostic description), Validation characters (diagnostic description of the adult female), Comparison (with similar species), U.S.A. quarantine notes, and Important References (a link to ScaleNet). In fact sheets, most morphological terms are hyperlinked to the glossary, and two or three figures are present, which can be enlarged by clicking on them: a line drawing with structures labeled, a habitus picture and a picture of the slide mounted, whole body of a mature female. In the enlargement of the whole body, diagnostic features are marked with squares. When the user scrolls the mouse over a square, an enlargement of the corresponding feature will pop up in a window (Fig. 2).

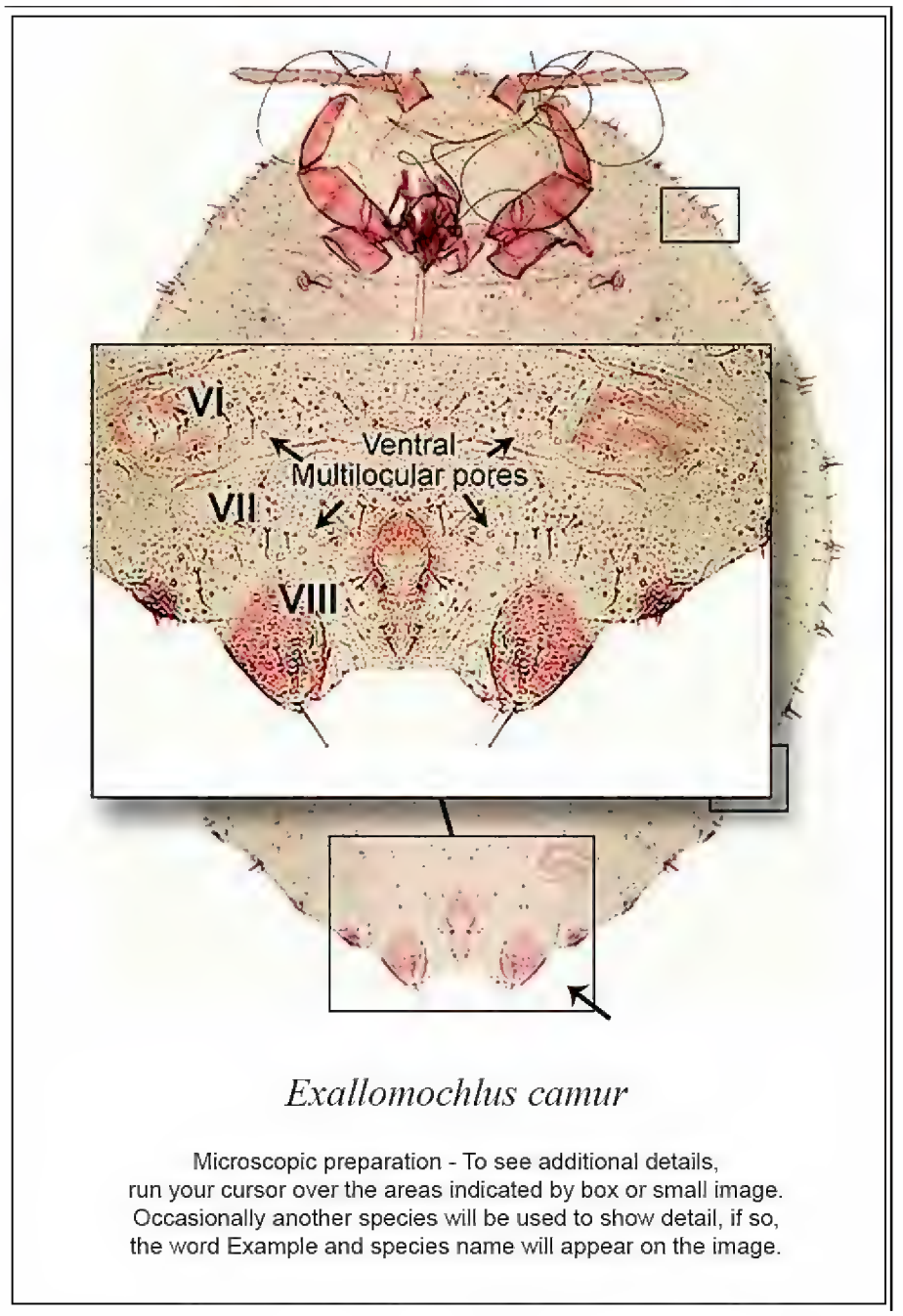
VI
Ventral
Multilocular pores
VII
VIII
Exallomochlus camur
Microscopic preparation - To see additional details,
run your cursor over the areas indicated by box or small image.
Occasionally another species will be used to show detail, if so,
the word Example and species name will appear on the image.

Figure 2. Screen snapshots of the diagnostic page of *Exallomochlus camur* Williams in the Mealybugs and Mealybug-like families of Scale Insects, edition 2 (viewed from Firefox 27.0.1 on April 10, 2014). Diagnostic features are marked by rectangles; rolling the mouse over each rectangle will bring up an enlargement of the feature.

The image gallery offers a quick way to perform identifications by matching the specimen in hand with a drawing or a photograph. Images can be filtered in two ways: by including or excluding images of the habitus, whole body picture or drawing; and by selecting a package (each package corresponds to a Lucid key and associated fact sheets and images).

From the Lucid On-line Player the Lucid key looks very similar to its Lucid3 Player counterpart (Fig. 3). The terminal taxa are represented as Entities on the right windows, whereas the features are represented as Features on the left windows. When a feature state is selected, the entities that do not have that feature will be moved into the "Entities Discarded" window (lower right), and the character state selected will be moved to the lower left window. All entities and feature states are richly illustrated with photographs and/or drawings. Clicking on the image thumbnail of a state brings up a larger image. Clicking on the taxon thumbnail brings up a larger window with

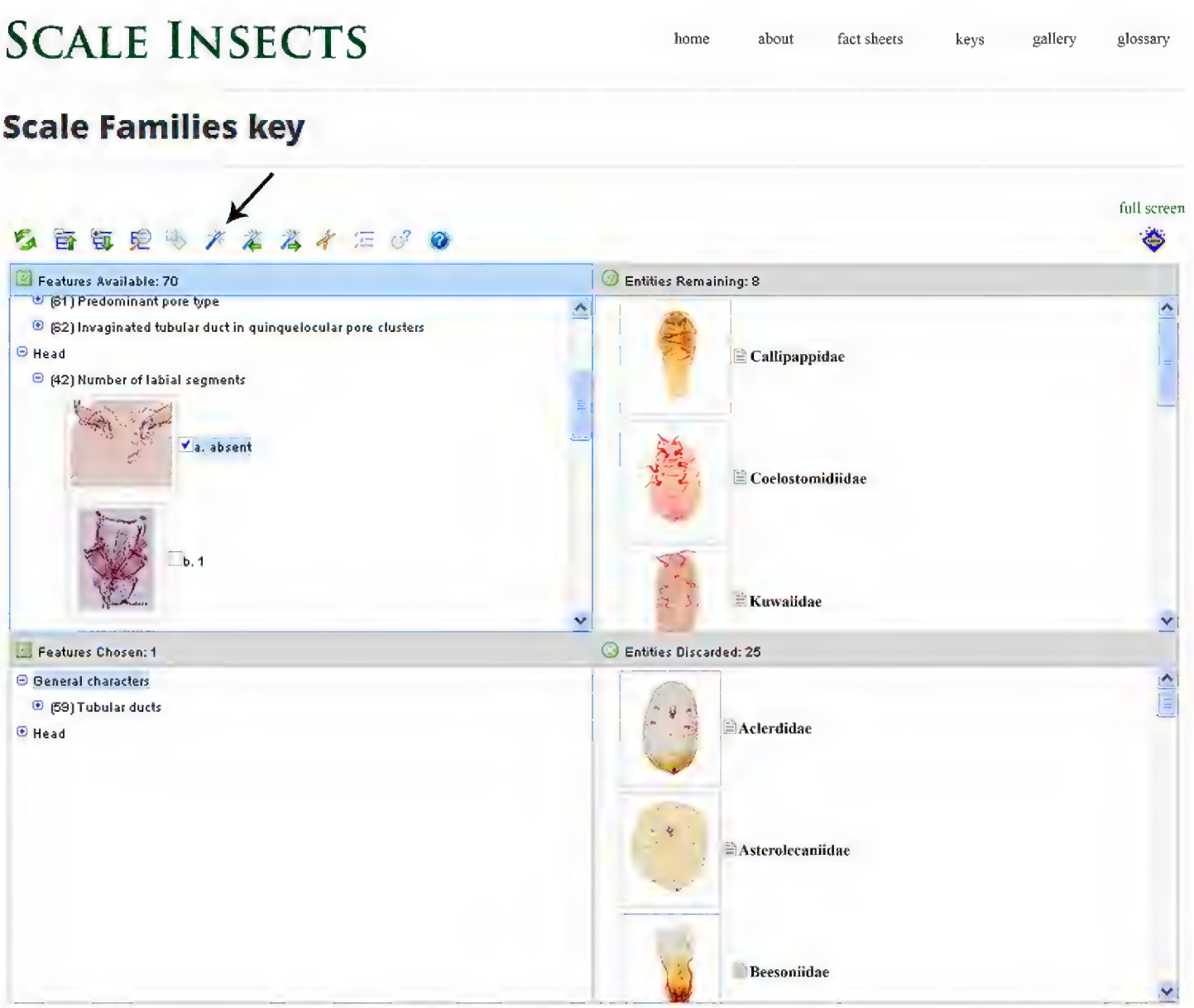

Figure 3. Screen snapshot of the Lucid Key to families, Scale Insects, edition 2 (viewed from Firefox 27.0.1 on April 10, 2014). Features can be selected in any order or they can be selected by the program by clicking on the "best character" icon (indicated with black arrow). Entities with the character states selected remain in the "entities remaining" window (upper right window) whereas those that do not match the states selected are sent to the "entities discarded" (lower right window).

thumbnails of a line drawing with important structures labeled, a whole body picture, and a habitus picture (when available). Clicking on the name of the taxon brings up a link to the fact sheet for that taxon.

Conclusions

Protecting the borders of large countries such as the United States from invasive scales often requires a very broad knowledge of the taxonomy the group, and consultation of books and papers that are scattered all over the place. Scale Insects, edition 2 may facilitate the job of target users, which include USDA APHIS pest survey specialists, identifiers at ports of entry, state and county identifiers, students, and scientists, in three ways. First, it condenses, in one online resource, a wide array of information on target species from various zoogeographical regions. Second, it maintains current

taxonomic information through links to ScaleNet, a relational database that is updated regularly. Third, additional species of concern can be easily added to the Lucid keys and fact sheets. We believe that our tool will facilitate insect pest identifications and we hope that it will inspire taxonomists in other groups to build similar tools.

Acknowledgments

This contribution was made possible, in part, by a Cooperative Agreement from the United States Department of Agriculture's Animal and Plant Health Inspection Service (APHIS). It may not necessarily express APHIS' views. We are grateful to Terrence Walters, coordinator of the USDA APHIS PPQ CPHST Identification Technology Program, for providing logistical support to the authors for the successful development and deployment of Scale Insects, edition 2. We also thank Amanda Redford, George Venable, Ray Gill and Gregory Evans, co-authors in the electronic version of the tool, for their work and dedication. Sincere thanks to Gail Coleman, Adam Holmes and Maaka Letuligasenoa (all California Department of Food and Agriculture) for administrative assistance. We also thank Gary Miller (USDA) for allowing the use of USDA-BARC facilities and collection, and Barbara Denno for general assistance, particularly updating ScaleNet to make our hyperlinks current.

References

Ben-Dov Y, Miller DR, Gibson GAP (2012) ScaleNet. http://www.sel.barc.usda.gov/scalenet/scalenet.htm [accessed on 27 May 2014]

Borchsenius NS (1960) Fauna of USSR, Homoptera, Kermococcidae, Asterolecaniidae, Lecanidodiaspididae, Aclerdidae. Akademiia Nauk SSSR, Zoologicheskii Institut (Series), Leningrad, 282 pp.

Bullington SW, Kosztarab M (1985) Studies on the morphology and systematics of scale insects – No. 12.I. Revision of the family Kermesidae (Homoptera) in the Nearctic region based on adult and third instar females. Bulletin of the Virginia Polytechnic Institute and State University Agricultural Experiment Station 85-11: 1–118.

Cerretti P, Tschorsnig H-P, Lopresti M, Di Giovanni F (2012) MOSCHweb – a matrix-based interactive key to the genera of the Palaearctic Tachinidae (Insecta, Diptera). ZooKeys 205: 5–18. doi: 10.3897/zookeys.205.3409.

Chamberlin JC (1923) A systematic monograph of the Tachardiinae or lac insects (Coccidae). Bulletin of Entomological Research 14: 147–212. doi: 10.1017/S000748530005625X

Chrétiennot-Dinet M-J, Desreumaux N, Vignes-Lebbe R (2014) An interactive key to the *Chrysochromulina* species (Haptophyta) described in the literature. PhytoKeys 34: 47–60. doi: 10.3897/phytokeys.34.6242

Cox JM (1987) Pseudococcidae (Insecta: Hemiptera). In: Duval CT (Ed.) Fauna of New Zealand. 11. DSIR Science Information Publishing Centre, Wellington, New Zealand, 229 pp.

Cox JM (1989) The mealybug genus *Planococcus* (Homoptera: Pseudococcidae). Bulletin British Museum (Natural History). Entomology 58(1): 1–78.

Dallwitz MJ, Paine TA, Zurcher EJ (2013) Principles of Interactive Keys. http://delta-intkey.com/www/interactivekeys.pdf [accessed on 27 May 2014]

Danzig EM (1993) Fauna of Russia and Neighbouring Countries. Rhynchota, Volume X: Suborder Scale Insects (Coccinea): Families Phoenicococcidae and Diaspididae. Nauka Publishing House, St. Petersburg, 452 pp.

De Lotto G (1965) On some Coccidae (Homoptera), chiefly from Africa. Bulletin of the British Museum (Natural History) Entomology 16: 175–239.

De Lotto G (1974) On the status and identity of the cochineal insects (Homoptera: Coccoidea: Dactylopiidae). Journal of the Entomological Society of Southern Africa 37: 167–193.

Evans G.A., Dooley JW (2013) Potential invasive species of scale insects for the USA and Caribbean Basin. In: Peña JE (Ed.) Potential invasive pests of agricultural crops. CABI, Wallingford, 320–341.

Ferris GF (1950) Atlas of the Scale Insects of North America. (ser. 5) [v. 5]. The Pseudococcidae (Part I). Stanford University Press, Palo Alto, California, 278 pp.

Foldi I (2005) The Matsucoccidae in the Mediterranean basin with a world list of species (Hemiptera: Sternorrhyncha: Coccoidea). Annales de la Société Entomologique de France 40(2): 145–168. doi: 10.1080/00379271.2004.10697412

Gill RJ (1988) The Scale Insects of California: Part 1. The Soft Scales (Homoptera: Coccoidea: Coccidae). California Department of Food & Agriculture, Sacramento, CA, 132 pp.

Gill RJ, Nakahara S, Williams ML (1977) A review of the genus *Coccus* Linnaeus in America north of Panama (Homoptera: Coccoidea: Coccidae). Occasional Papers in Entomology, State of California, Department of Food and Agriculture 24: 1–44.

Gimpel WF, Miller DR, Davidson JA (1974) A systematic revision of the wax scales, genus *Ceroplastes*, in the United States (Homoptera; Coccoidea; Coccidae). University of Maryland, Agricultural Experiment Station, Miscellaneous Publication 841: 1–85.

Hamon AB, Williams ML (1984) The soft scale insects of Florida (Homoptera: Coccoidea: Coccidae). Arthropods of Florida and Neighboring Land Areas. Florida Deptartment of Agriculture & Consumer Services, Division of Plant Industry, Gainesville, 194 pp.

Hardy NB (2013) The status and future of scale insect (Coccoidea) systematics. Systematic Entomology 38(3) 453–458. doi: 10.1111/syen.12022

Hardy NB, Kondo T. (2009) Australian Soft Scale (Coccidae) Genera Version: 1. http://keys.lucidcentral.org/key-server/keys.jsp?page=2&sort=title [accessed on 27 May 2014]

Hodges GS, Hodgson CJ (2010) *Phalacrococcus howertoni*, a new genus and species of soft scales (Hemiptera: Coccidae) from Florida. Florida Entomologist 93(1): 8–23. doi: 10.1653/024.093.0102

Hodgson CJ (1994) The scale insect family Coccidae: an identification manual to genera. CAB International, Wallingford, Oxon, 639 pp.

Hodgson CJ (2012) Comparison of the morphology of the adult males of the rhizoecine, phenacoccine and pseudococcine mealybugs (Hemiptera: Sternorrhyncha: Coccoidea), with the recognition of the family Rhizoecidae Williams. Zootaxa 3291: 1–79.

Howell JO, Kosztarab M (1972) Morphology and systematics of the adult females of the genus *Lecanodiaspis* (Homoptera: Coccoidea: Lecanodiaspididae). Research Division Bulletin Virginia Polytechnic Institute and State University, Blacksburg 70: 1–248.

Jakubski AW (1965) A Critical Revision of the Families Margarodidae and Termitococcidae (Hemiptera, Coccoidea). Trustees of the British Museum (Natural History), London, 187 pp.

Kaydan MB, Gullan PJ (2012) A taxonomic revision of the mealybug genus *Ferrisia* Fullaway (Hemiptera: Pseudococcidae), with descriptions of eight new species and a new genus. Zootaxa 3543: 1–65.

Kondo T, Gullan PJ, Williams DJ (2008) Coccidology. The study of scale insects (Hemiptera: Sternorrhyncha: Coccoidea). Revista Corpoica - Ciencia y Tecnología Agropecuaria 9: 55–61.

Kosztarab M (1977) The current state of coccoid systematics. Virginia Polytechnic Institute and State University, Research Bulletin 127: 1–4.

Kosztarab M (1990) Economic Importance. In: Rosen D (Ed.) Armored Scale Insects Their Biology, Natural Enemies and Control. Volume B. Elsevier, Amsterdam, 307–311.

Kosztarab M (1996) Scale insects of Northeastern North America. Identification, biology, and distribution. Virginia Museum of Natural History, Martinsburg, Virginia, 650 pp.

Kozár F (2004) Ortheziidae of the World. Plant Protection Institute, Hungarian Academy of Sciences, Budapest, Hungary, 525 pp.

Kozár F, Kaydan MB, Konczné Benedicty Z, Szita E (2013) Acanthococcidae and Related Families of the Palaearctic Region. Plant Protection Institute, Centre for Agricultural Research, Hungarian Academy of Sciences, Budapest, Hungary, 679 pp.

Kozár F, Konczné Benedicty Z (2007) Rhizoecinae of the World. Plant Protection Institute, Hungarian Academy of Sciences, Budapest, 617 pp.

Lambdin PL, Kosztarab M (1977) Morphology and systematics of the adult females of the genus *Cerococcus* (Homoptera: Coccoidea: Cerococcidae). Research Division Bulletin Virginia Polytechnic Institute and State University, Blacksburg 128: 1–252.

Mamet JR (1954) A monograph of the Conchaspididae Green (Hemiptera: Coccoidea). Transactions of the Royal Entomological Society of London 105: 189–239. doi: 10.1111/j.1365-2311.1954.tb00764.x

McConnell HS (1954) A classification of the coccid family Aclerdidae (Coccoidea, Homoptera). Bulletin of the Maryland Agriculture Experiment Station A75: 1–121.

McKenzie HL (1967) Mealybugs of California with Taxonomy, Biology, and Control of North American Species (Homoptera: Coccoidea: Pseudococcidae). University of California Press, Berkeley, 526 pp.

Miller DR (1975) A revision of the genus *Heterococcus* Ferris with a diagnosis of *Brevennia* Goux (Homoptera: Coccoidea: Pseudococcidae). United States Department of Agriculture Technical Bulletin 1497: 1–61.

Miller GL, Miller DR (2003) Invasive soft scales (Hemiptera: Coccidae) and their threat to U. S. agriculture. Proceedings of the Entomological Society of Washington 105: 832–846.

Miller DR, Giliomee JH (2011) Systematic revision of the mealybug genus *Delottococcus* Cox & Ben-Dov (Hemiptera: Pseudococcidae). African Entomology 19(3): 614–640. doi: 10.4001/003.019.0306

Miller DR, McKenzie HL (1973) Seventh taxonomic study of North American mealybugs (Homoptera: Coccoidea: Pseudococcidae). Hilgardia 41: 489–542.

Miller DR, Miller GL, Watson GW (2002) Invasive species of mealybugs (Hemiptera: Pseudococcidae) and their threat to U.S. agriculture. Proceedings of the Entomological Society of Washington 104: 825–836.

Miller DR, Rung A, Venable GL, Gill RJ (2007) Scale Insects: Identification tools, images, and diagnostic information for species of quarantine significance. CDROM. USDA, SEL, APHIS. http://www.sel.barc.usda.gov/ScaleKeys/index.html [accessed on 27 May 2014]

Miller DR, Rung A, Parikh G, Venable G, Redford AJ, Evans G, Gill RJ (2014) Scale Insects, edition 2. USDA APHIS PPQ Identification Technology Program (ITP). Fort Collins, CO. http://idtools.org/id/scales/ [accessed on27 May 2014]

Morrison H (1928) A classification of the higher groups and genera of the coccid family Margarodidae. United States Department of Agriculture Technical Bulletin 52: 1–239.

Penev L, Cerretti P, Tschorsnig H-P, Lopresti M, Di Giovanni F, Georgiev T, Stoev P (2012) Publishing online identification keys in the form of scholarly papers. ZooKeys 205: 1–3. doi: 10.3897/zookeys.205.3581

Penev L, Sharkey M, Erwin T, van Noort S, Buffington M, Seltmann K, Johnson N, Taylor M, Thompson C, Dallwitz M (2009) Data publication and dissemination of interactive keys under the open access model. ZooKeys 21: 1–17. doi: 10.3897/zookeys.21.274

Richard C (1971) Contribution à l'étude morphologique et biologique des Stictococcinae (Hom. Coccoidea). Annales de la Société Entomologique de France 7: 571–609.

Richard C (1976) Révision du groupe des Stictococcus, et création de taxa nouveaux (Homoptera, Coccoidea). Annales de la Société Entomologique de France, 12: 653–669.

Stumpf CF, Lambdin PL (2006) Pit Scales (Sternorrhyncha: Coccoidea) of North and South America. Tennessee Agricultural Experiment Station, University of Tennessee Institute of Agriculture, Knoxville, Tennessee, 231 pp.

Takagi S (1960) A contribution to the knowledge of the Diaspidini of Japan (Homoptera: Coccoidea) Pt. 1. Insecta Matsumurana 23: 67–100.

Walter DE, Winterton S (2007) Keys and the Crisis in Taxonomy: Extinction or Reinvention? Annual Review of Entomology 52: 193–208. doi: 10.1146/annurev.ento.51.110104.151054

Williams DJ (2004) Mealybugs of Southern Asia. The Natural History Museum, Southdene, Kuala Lumpur, 896 pp.

Williams DJ, Granara de Willink MC (1992) Mealybugs of Central and South America. CAB International, Wallingford, Oxon, 635 pp.

Williams DJ, Miller DR (2002) Systematic studies on the *Antonina crawi* Cockerell (Hemiptera: Coccoidea: Pseudococcidae) complex of pest mealybugs. Proceedings of the Entomological Society of Washington 104(4): 896–911.

Williams DJ, Watson GW (1988) The Scale Insects of the Tropical South Pacific Region. Pt. 2: The Mealybugs (Pseudococcidae). CAB International, Wallingford, 260 pp.

Williams DJ, Watson GW (1990) The Scale Insects of the Tropical South Pacific Region. Pt. 3: The Soft Scales (Coccidae) and Other Families. CAB International, Wallingford, 267 pp.